The
U.S. GOVERNMENT

IS ABSOLVED

FROM ANY LITIGATION WHICH MAY ENSUE FROM THE CONTRACTORS IN-FRINGING ON THE FOREIGN PATENT RIGHTS WHICH MAY BE INVOLVED.

15

REEL – C

483

A.T.I.

13844

LISTED
N 1456

DESCRIPTION AND OPERATION OF THE GENERAL PURPOSE VARIABLE DELAY UNIT

REPORT
891

RADIATION LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE · MASSACHUSETTS

NDRC
Div. 14
OEMsr-262

Radiation Laboratory

Report 891 March 26, 1946

DESCRIPTION AND OPERATION OF THE GENERAL PURPOSE VARIABLE DELAY UNIT

Abstract

The general purpose variable delay unit is a device designed for obtaining a trigger pulse delayed in time from an input trigger. The amount of delay time can be varied continuously from a fixed minimum value of about 10 microseconds (approximately 1 statute mile) to a maximum of about 2400 microseconds (approximately 200 nautical miles), depending of course on the period between input triggers. In fact, the maximum delay can be up to 85 percent of the duration of this period. The unit will accept a positive or negative trigger rising to at least 50 volts in .5 microsecond and supplies a positive or negative trigger output. The output triggers rise to 90 percent of maximum amplitude in .2 microsecond with positive output of 70 volts at 75 ohms impedance and negative output of 200 volts at 4000 ohms impedance. The delay circuit used is the phantastron using the type 6SA7 tube. The unit operates from a line voltage of 115 volts at 50 to 1200 cycles per second and when constructed as illustrated will weigh about 20 pounds.

R. P. Abbenhouse

Approved by.

T Soller
Leader, Group 62

L. J. Haworth
Head, Division 6

Title page
10 numbered pages
7 pages of figures

DESCRIPTION AND OPERATION OF THE GENERAL PURPOSE VARIABLE DELAY UNIT

1. Introduction.

The delay control in the general purpose delay unit is derived from an electronically regulated d.c. variable control voltage in a phantastron circuit using a 6SA7 tube. The phantastron circuit is used because it provides for a very linear variation of delay time, and hence, allows accurate and reliable calibration of a dial associated with the control voltage variable.

A detailed discussion of the phantastron principle can be found in Radiation Laboratory report, No. 63-21.

In addition to the phantastron circuit, other circuits are required to provide proper input voltages and for the derivation of the output trigger from the output voltage of the phantastron circuit. The block diagram in Fig. 1 indicates the sequence of circuit operation.

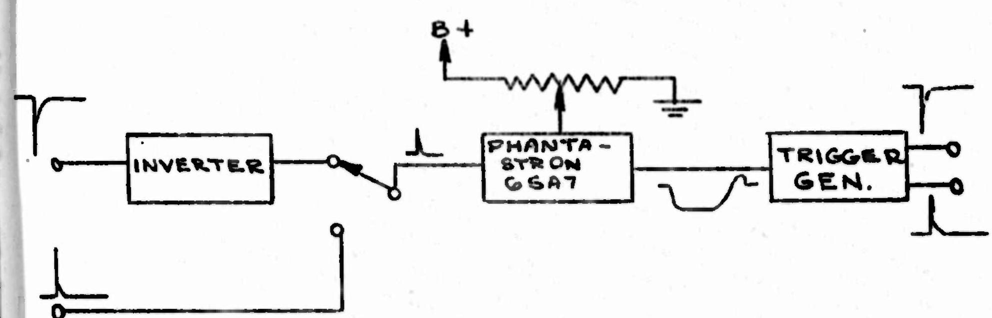


Fig. 1

In this unit a 30 volt positive trigger is applied to grid No. 2 of the 6SA7. This grid acts as a second control element in this tube. The resulting action results in a negative waveform at the cathode whose duration is proportional to the value of the control voltage derived from a potentiometer across the supply voltage. The positive variation of cathode voltage corresponding to the recovery action of the circuit is linear with time. Furthermore, the slope of this variation is constant with respect to control voltage and hence the duration of the cycle. At some point along this slope the bias on a trigger generator stage is overcome, resulting in one cycle of operation of the trigger generating circuit.

The trigger generator is a blocking oscillator normally biased to cutoff and its operation is thus delayed from the input trigger by an amount of time determined by the control voltage in the phantastron circuit.

A fast rising pulse occurring in the cathode circuit of the blocking oscillator forms the positive trigger output. A negative trigger is obtained by inverting this positive trigger in the second half of V1.

2. Circuits.

2.1 Inverters. As mentioned in section 1 two inverters are used in this unit and utilize the two sections of a 6SN7 tube. One provides the positive trigger for the phantastron from the negative trigger input terminal while the other inverts the positive output trigger to make a negative trigger available from the delay unit.

In the first case the triode section is normally conducting at zero bias. The negative input momentarily cuts off plate current allowing a fast rising positive signal to develop in the plate circuit. The plate load consists of R5 in parallel with R6 and R10 through C5. C4 in the grid circuit of V1A prevents parasitic oscillation that was previously observed at this point.

In the second application of the inverter the second section of V1 is biased beyond plate current cutoff. The grid is direct coupled to the cathode circuit of the trigger generator tube. This point of connection is a fraction of a volt above ground potential except when a current pulse flows through it due to the operation of the trigger generator.

2.2 Phantastron delay circuit. The phantastron circuit consists of a 6SA7 (V2) in conjunction with both sections of a 6SN7 (V3). Following, for the most part, Radiation Laboratory report 63-21, we divide the operation of the circuit into six stages. The basic circuit is shown in Fig. 2 and the waveforms at the various electrodes are shown in Fig. 3

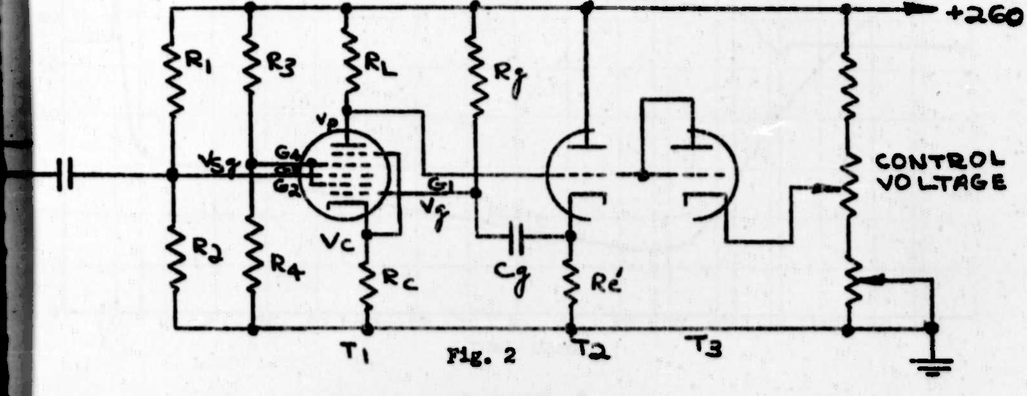
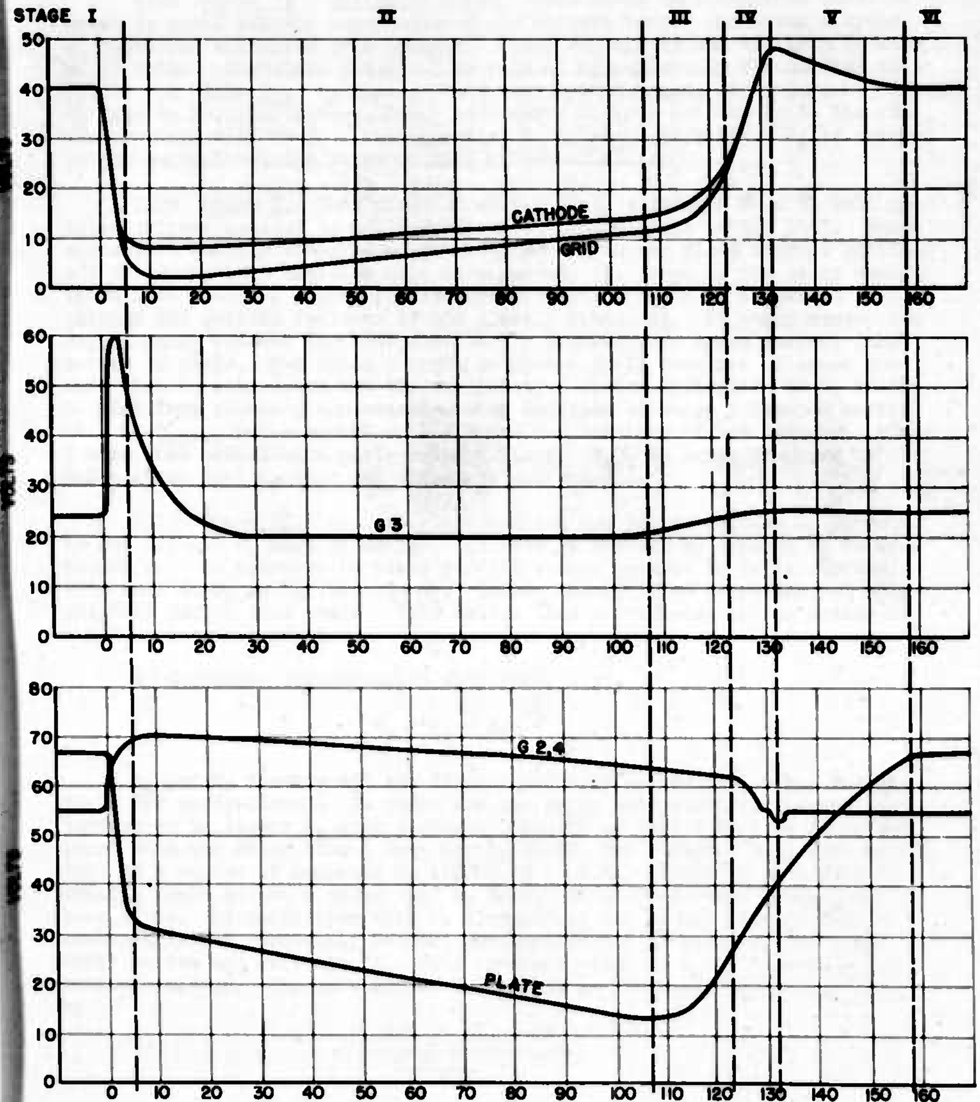


Fig. 2



STAGE I
II
III
IV
V
VI
VOLTS
CATHODE
GRID
G 3
G 2,4
PLATE
TIME - USEC

FIGURE 3

2.21 <u>Stage VI</u> - <u>Quiescent Stage</u>. This stage is considered first in order to point out the conditions of the circuit before and after a cycle of operation initiated by a trigger. Plate current is cut off by a G_3 bias of 15 volts. The plate potential is held at approximately the control voltage by the diode T_3. G_1 bias is held near zero by means of G_1 current through R_g tied to B+. The screen, $G_{2,4}$, is drawing about 4 ma. mostly to the collector plate tied to G_2. Consequently, V_c is about 40 volts. C_g is charged to the control voltage minus initial G_1 potential.

2.22 <u>Stage I</u>. This stage of operation is initiated by a 30 volt positive trigger applied to G_3, the second control element in the 6SA7. Space current is quickly transferred from the screen to the plate circuit cutting off the diode in a fraction of a microsecond. V_p drops as the stray capacitance from plate to ground is discharged. This drop in V_p is passed to G_1 through the cathode follower T2 and closely behind G_1. In other words, the signal on G_3 removes its bias momentarily transferring space current from screen to plate. But plate current is such a small fraction of space current that V_c also drops and the regenerative action from plate to G_1 keeps G_1 bias from changing appreciably. The duration of stage I depends mostly on $R_L C_{stray}$ but somewhat on the shape and duration of the trigger. Stage I ends when equilibrium plate current flows. $R_g C_g$ is large compared to $R_L C_{stray}$ so that C_g does not discharge appreciably.

2.23 <u>Stage II</u>. An unstable condition now exists because G_1 current is cut off and C_g must discharge. It does so through R_g causing V_g to rise toward B+. An increase in plate current occurs so that V_p falls further. This fall in V_p is fed back to G_1. Screen current also increases but only slightly during this stage. This action then corresponds to the action in a Miller feedback circuit.

V_p decreases exponentially with time, i.e.,

$$V_p = K_1 + K_2 e^{-\frac{t}{T}}$$

K_1 and K_2 involve all the circuit and tube parameters. (See report 63-21 for derivations.) In order for the delay characteristic of the phantastron to be linear V_p must decrease linearly so that T must be large compared with any delay time t that may be used. For a high μ tube such as the 6SA7 in a region of moderate G_m (1000), $T \simeq \mu C_g R_g$. Stage II ends when V_p and V_{sg} reach so low a value that i_p ceases to increase with decreasing bias on G_1. By definition this is a region of low G_m and thus V_p falls nonlinearly and eventually becomes constant (about 27 volts in the delay unit) at the end of stage II. This constant value of V_p is independent of control voltage. The duration of this stage is given approximately below by

$$\frac{C.V. - \Delta V_I - 27}{E_b/R_g C_g}$$

C.V. = control voltage

ΔV_I = drop in V_p during stage I.

2.24 Stage III. During this stage V_p is at its lowest possible value so that no feedback can occur between plate and grid. V_g rises toward B+ with the time constant R_gC_g with V_c following along closely and the screen taking most of the increasing space current, thereby decreasing V_{sg}. i_p should increase, but G3 bias is decreasing as U_c increases so that i_p decreases slightly, causing V_p to rise. V_c increases finally to the point where G3 bias approaches plate current cut off, marking the end of stage III.

2.25 Stage IV. The regenerative action again takes hold at the beginning of this stage and V_c rises with V_p. V_{sg} falls sharply now since i_p is being cut off and the screen is taking up the space current as G3 bias increases. V_p rises at a rate determined by R_L X C stray, as in stage I, and the sharpness of G3 i_p cut off bias. This stage ends when screen current becomes constant regardless of G_1 bias; G_1 current begins to flow again eventually clamping G_1 to the quiescent bias condition at the end of stage V. V_c at the beginning of and its rate of rise during this stage in independent of control voltage, and at some point of this rise, the bias of the following amplifier stage, V_4 is overcome so that the output trigger is formed.

2.26 Stage V. V_p continues to rise according to R_L X C stray until it is caught by the diode and clamped to the control voltage. V_c has reached its quiescent voltage sometime during stage IV, but overshoots it in following G_1 beyond its quiescent point due to feedback from the plate through the cathode follower, T2. The shape of this overshoot is due to the current pulse in G_1 and its duration turns out to be proportional to the duration of the entire cycle, and hence, proportional to the control voltage. This fact is unimportant since the maximum possible duty cycle remains about 85 percent for any input trigger repetition frequency.

2.3 Amplifier and Trigger Generator. The output trigger is formed in V_4 and V_5 which are both type 6AG7 tubes. Since interelectrode capacity is low in this type it is possible to obtain very rapid action especially when large amounts of feedback are introduced as with a secondary winding of a pulse transformer. In the circuit used in the delay unit, V_4 acts as a current amplifier which is normally cut off. When the cathode of V_2 rises toward its stable value at the end of stage V, V_4 grid is carried into the plate current conducting region and a fast current pulse is pulled through the plate winding of T_1. Coupling to the grid winding is such that V_5 grid is driven positive momentarily causing plate current to flow in V_5, further amplifying the current pulse in V_4. Saturation current is quickly reached and when di_p/dt becomes zero, grid current in V_5 and R28 discharges C_{12}, and the feedback action again takes hold so as to drive V_4 grid strongly negative, cutting off V_5 plate current. Now C12 can discharge only through R28, resulting in a comparatively slow recovery of V_5 grid. In the meantime, during the positive portion of the grid signal, a current pulse will be formed across R27. This current pulse reaches a peak about .5 ampere causing a 75 volt trigger to appear at this point at a very low impedance level, which is of the order of 50 ohms, i.e.,

$$Z_o = \frac{R_{27}(r_p + Z_t)}{(\mu+1)\, R_{27} + r_p + Z_t}$$

This positive trigger is available at the panel of the instrument and is also direct coupled to the grid of the inverter as described in 2.1 to obtain a negative trigger for external use. Since no oscillation in T_1 can take place while the grid of V_5 is held negative by C_{12}, plate current in V_4 deteriorates to a stable value ($\cong 0$) and will not change again until the end of the next cycle of operation of the phantastron.

3. General.

It is essential to use high quality components in this unit if reasonable reliability of calibration of delay time is to be expected. This is especially true for the phantastron circuit itself. For minimum variation due to temperature changes the resistors specified for R_7 to R_{19} inclusive should be of the types recommended in the parts list at the end of this manual. C_5 and C_6 should be of high grade mica such as JAN CM30E and JAN CM35E, respectively.

When tube replacements become necessary for V_2 and V_3, R_{14} and R_{19} can be readjusted to reset the delay to the dial calibration.

Standard receiving type tubes were used since they are more generally available. Miniature equivalents of these tubes could be used with some circuit modifications if space considerations demand it. In fact, some advantage may be gained in respect to jitter due to line voltage ripple if a 6AS6 (miniature) is used instead of the 6SA7. It was found that heater supply ripple in the 6SA7 caused a constant jitter of about 0.1 µsec. in the output trigger. This jitter would disappear if d.c. were used for heater supply. It also seems to depend on the time constant in the grid circuit since it was .02 µsec. when C_5 is used and 0.1 when C_6 is used for the delay range.

Fig. 4 is a graph of the amount of delay as a function of the dial setting. It is thus seen that the delay is directly proportional to the dial reading. However, it will be noted that this delay is not linear for the first 3 to 12 divisions on both the low and high delay range corresponding to C_5 and C_6 respectively on switch Sw. 2.

To assist in locating trouble when maintenance is necessary, the table at the end of this text may be referred to for socket terminal voltages that should normally be read with a 20,000 ohm per volt multimeter. An oscilloscope would be desirable for checking wave forms that should appear at these points. Review of the preceding text and reference to the schematic diagram should indicate what these wave forms should be.

As shown in the photographs of Fig. 5, 6, 7, and 8 the packaging utilizes an SAR type chassis and dust cover. In addition, if the power transformer* specified in the parts list is used, this unit will be suitable

* At the time the model shown in the photographs was built this transformer was not yet available. About 4 pounds will be added to the weight of the unit if it is used.

for airborne use and should give trouble free service under most conditions normal to airborne applications. Under normal room conditions, the operating temperature inside the unit reaches approximately 58°C.

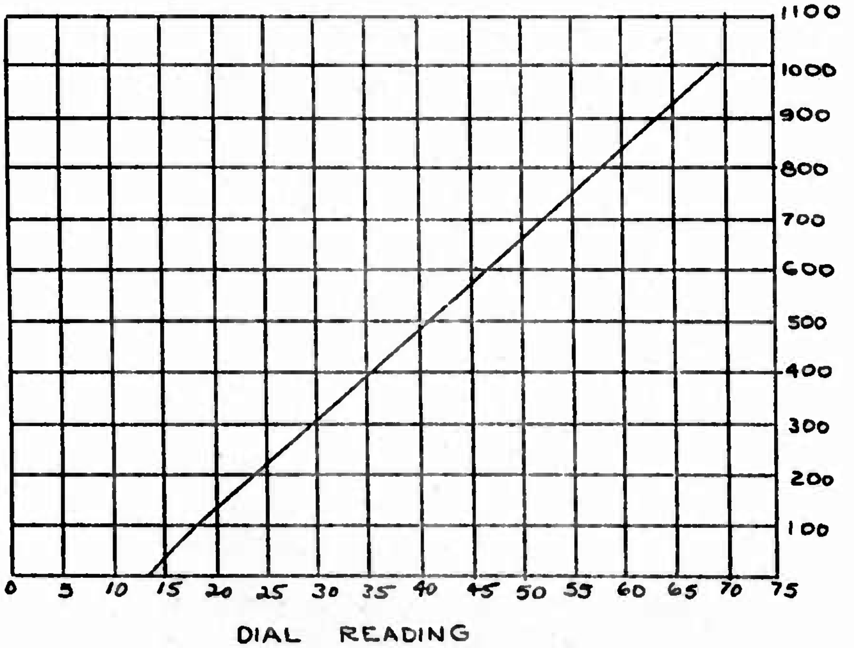


Fig. 4

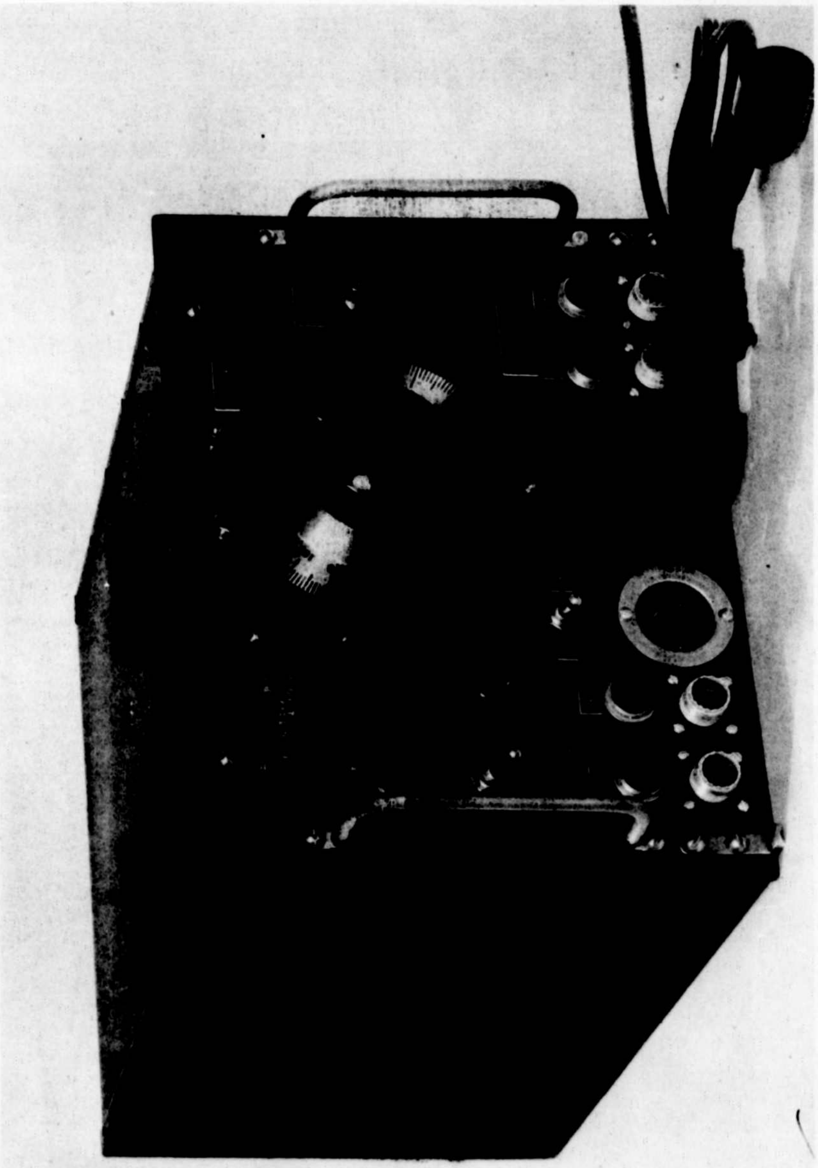


FIG. 5
VARIABLE TRIGGER DELAY UNIT

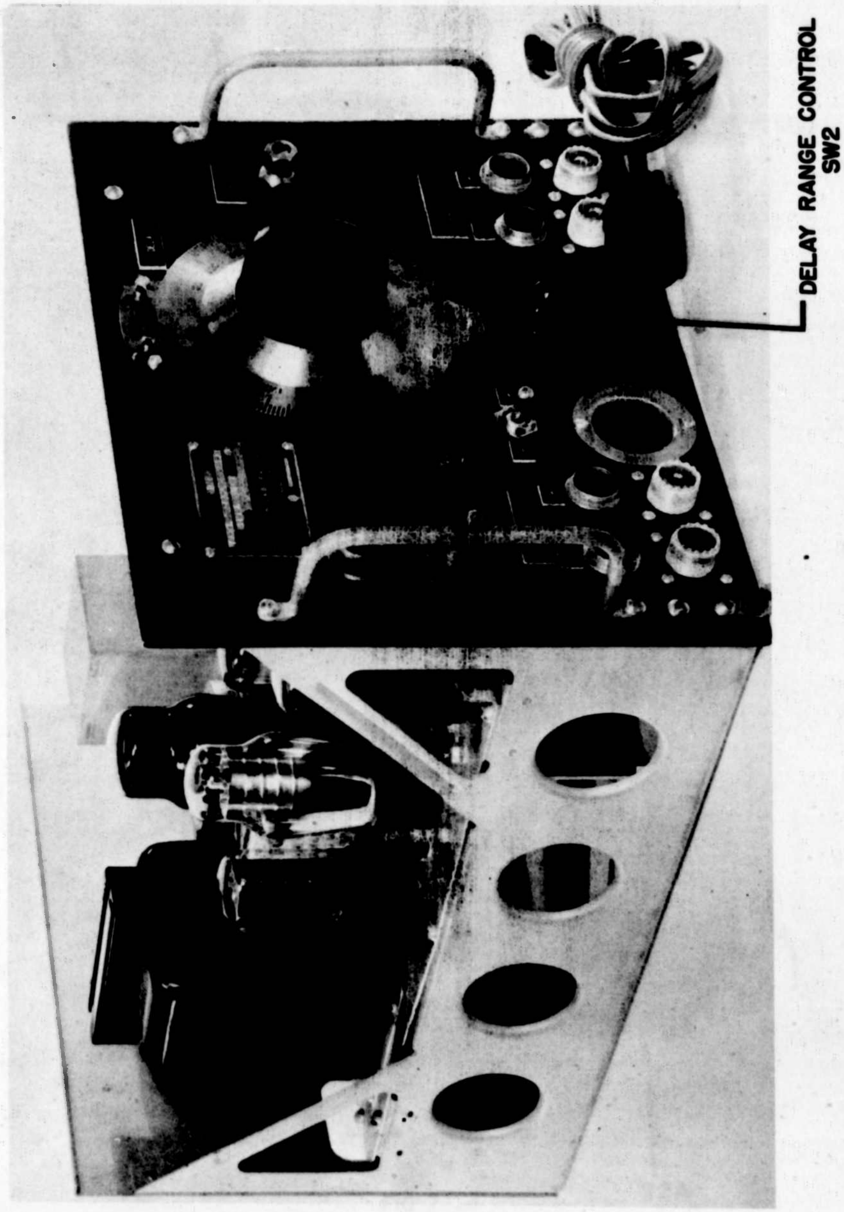


FIG. 6
OBLIQUE VIEW OF UNIT

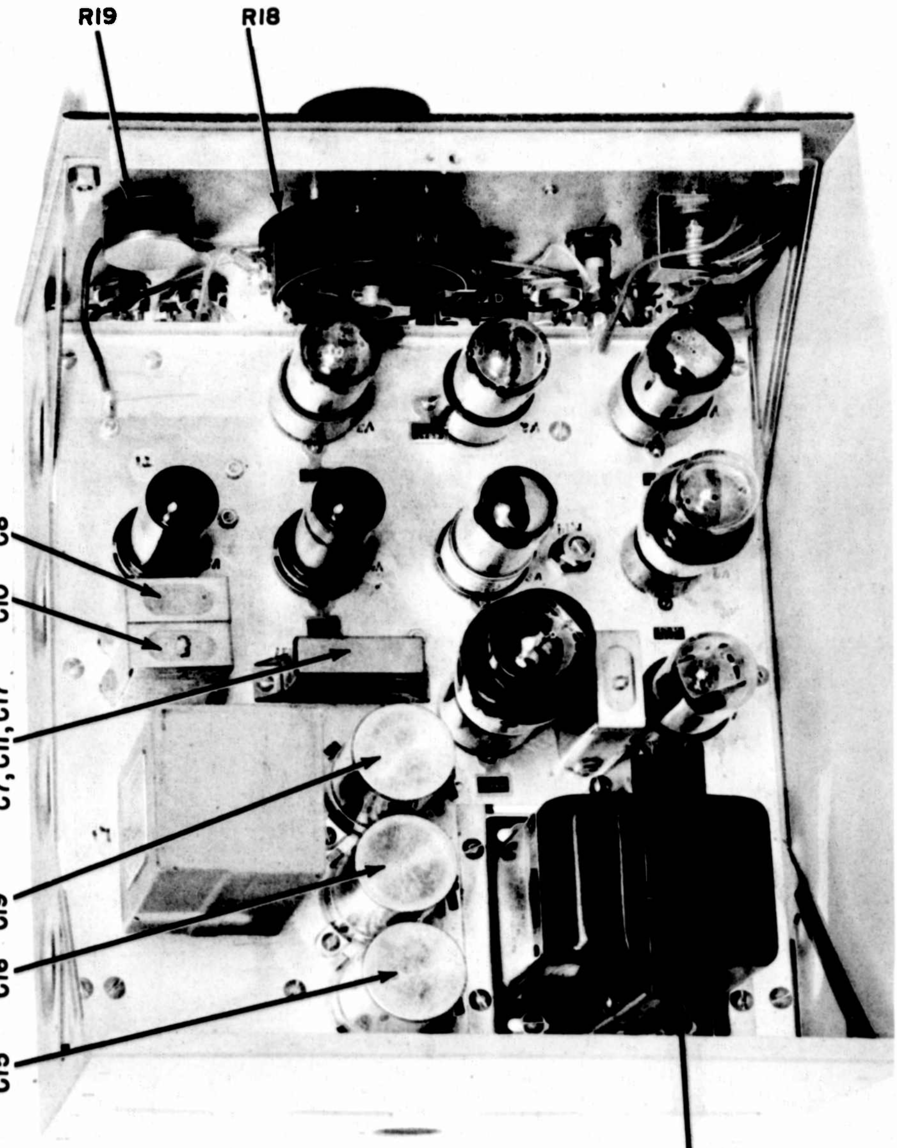


FIG. 7
TOP VIEW OF CHASSIS

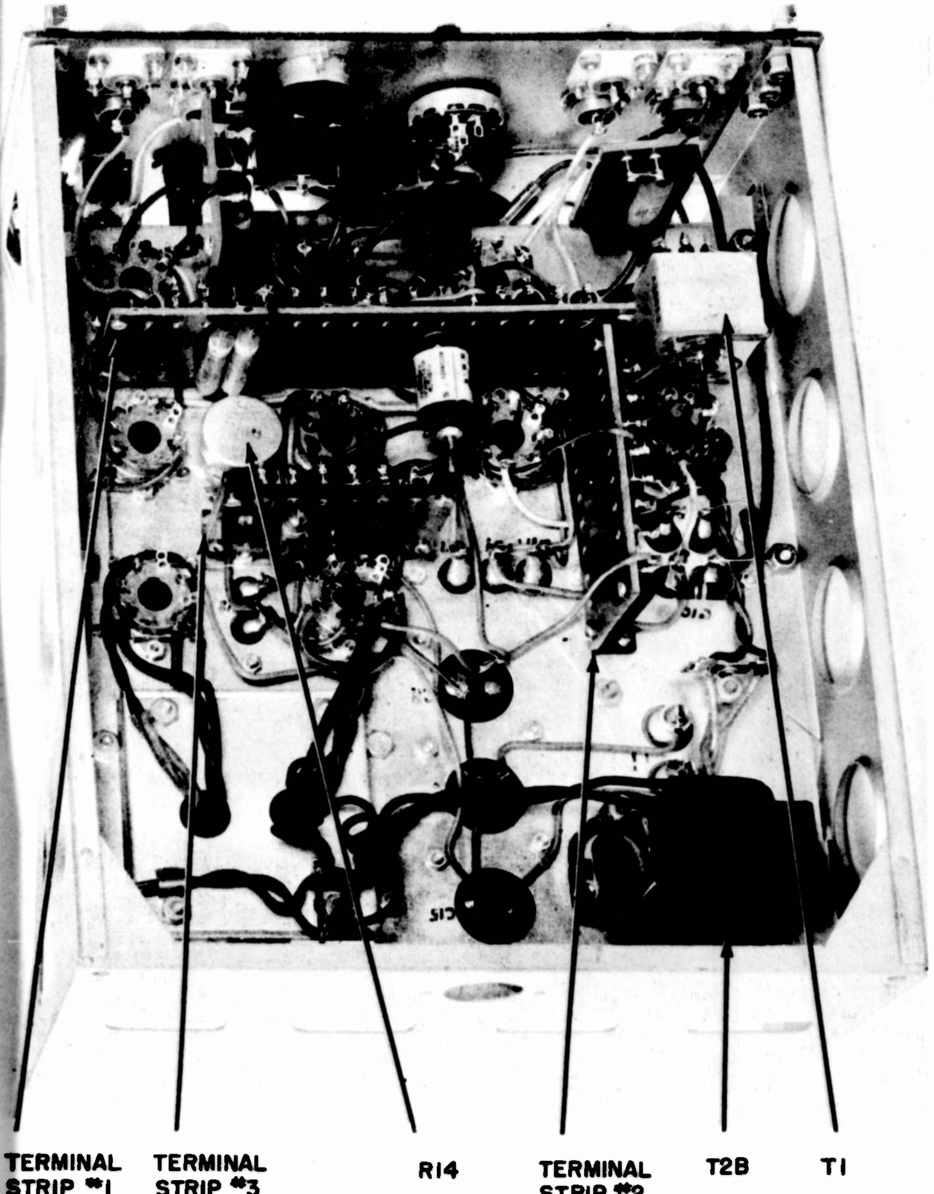


FIG. 8
BOTTOM VIEW OF CHASSIS

TUBE SOCKET VOLTAGES

Rep. rate = 500~
Delay ≅ 200μsec

	1	2	3	4	5	6	7	8
V1	-.6	100	0	.1	260	33	3ac	3ac
V2	0	3ac	85	60	37	38	3ac	24.5
V3	85	260	95	85	85	95	3ac	3ac
V4	49	3ac	0	38	49	205	3ac	255
V5	20	3ac	0	6.8	20	250	3ac	250
V6	0	360	0	320ac	0	320ac	0	360
V7	260	260*	350	340	250	0	260*	260
V8	0	3ac	205	102	105	135	3ac	250
V9	0	0	0	0	105	0	0	0

* 6.3V a.c. between these terminals

PARTS LIST - GENERAL PURPOSE VARIABLE DELAY

Component		Value	Power or Voltage Rating	Tolerance	JAN if any
R4		470K	1/2W	10 percent	RC20BF474K
R5		39K	2W	10 percent	RC41AE393K
R6		39K	2W	10 percent	RC41AE393K
R7		91K	1W	5 percent	RC30AE913J
R8	WW	15K	10W	5 percent	Koolohm Type KT
R9		1M	1W	5 percent	RC31AE105J
R10	WW	10K	10W	5 percent	Koolohm Type KT
R11		6.8K	2W	5 percent	RC41AE682J
R13		10K	1W	5 percent	RC30AE103J
R14	pot.	100K	1/2W	20 percent	
R15		1M	1/2W	1 percent	Precision wire wound
R16		47K	1W	5 percent	RC30AE473J
R17	WW	12.5M	10W	5 percent	Koolohm Type KT
R18	pot.	20K	4W	1 percent	DeJur Amsco No.281
R19	pot.	5K	2W	10 percent	RA2CA150502AK
R20		24K	1W	5 percent	RC30AE243J
R21		82K	1W	5 percent	RC30AE823J
R22		2K	1/2W	5 percent	RC20BF202J
R23		18K	1W	5 percent	RC30AE183J
R24		5.1K	1W	10 percent	RC30AE512K
R25		220K	1W	5 percent	RC30AE224J
R26		15K	1W	5 percent	RC30AE153J
R27		150Ω	1W	5 percent	RC30AE151J
R28		68K	1 2W	5 percent	RC20BF683J
R29		10K	1/2W	10 percent	RC20BF103K
R30		33K	1/2W	10 percent	RC20BF333K
R31		220K	1/2W	10 percent	RC20BF224K
R32		470Ω	1/2W	10 percent	RC20BF474K
R33		1M	1/2W	10 percent	RC20BF105K
R34		12K	2W	10 percent	RC41AE123K
R35		2.7K	1W	10 percent	RC30AE272K
R36		470K	1/2W	10 percent	RC20BF474K
R37		150K	1W	5 percent	RC30AE154J
R38		100K	1W	5 percent	RC30AE104J
C1		.001µf	600V	20 percent	metal cased oil impregnated paper
C2		200µµf		5 percent	CM20A201
C3		200µµf		5 percent	CM20A201
C4		43µµf		10 percent	CM20A430
C5		.0012µf		5 percent	CM30E122
C6		.0062µf		5 percent	CM35E622
C7		0.1µf			triple with C11&C17
C8		1.0µf			Tobe OM601
C9		100µµf		10 percent	CM20A101

Component	Value	Power or Voltage Rating	Tolerance	JAN if any
C10	1.0µf			Tobe OM601
C11	0.1µf		Triple with C7 and C17	
C12	.0018µf			CM30E182
C13	.01µf		Sprague metal cased oil paper	
C14	.01µf		" " " " "	
C15	8µf	450	Sprague D11167	
C16	8µf	450	" "	
C17	0.1µf	600		Aeravox 618CB
C18	0.1µf	600		Tobe OM610
C19	8µf	450	Sprague D11167	
L1	10H filter choke		50ma 240	Freed 12185
T1	Pulse transformer		Utah X154T	
T2	Power transformer R.L. dwg. A14730A to F incl, C6769A, C11952A, C12582D; or T70R78 and T19F97			
Sw 1	SPDT Toggle	ST12D		
Sw 2	Rotary SPDT			
Sw 3	SPST Toggle	ST12A		

9 Otal tube sockets molded mica base bakelite for 1" dia. chassis hole
Dial - National type N4
Fuse holder for 3AG fuses
Fuse 3AG 2 amp.
Pilot Bulb and holder Miniature bayonette
Chassis SARCM type B-1B
Dust cover SARCM type B-13

P1 Motor plug, male, chassis, twist lock, Hubbel miniature
P2 Motor plug, female, cable, twist lock, Hubbel miniature
P3 Line cord plug
Line cord 5 ft long

J1,J3,J5,J7 Amphenol type 8CS chassis cable connector
J2,J4,J6,J8 U.H.F. panel jack - AN No. SO-239, Navy No. 49194

V1 6SN7 tube
V2 6SA7 tube
V3 6SN6GTY tube
V4 6AG7 tube
V5 6AG7 tube
V6 5Y3G tube
V7 6Y6G tube
V8 6SJ7G tube
V9 VR105 tube

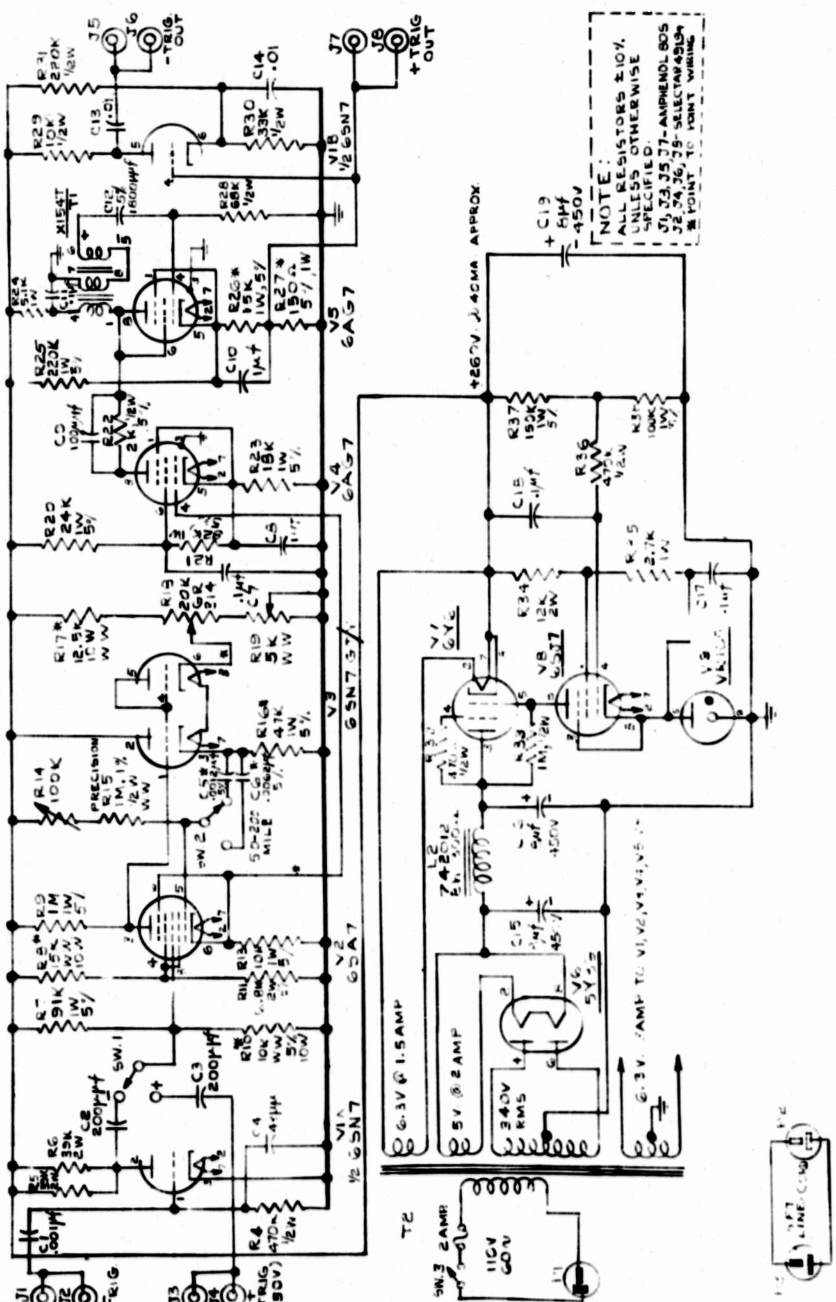
Hardware

All screws and nuts required must be cadmium plated. Use either elastic stop nuts or plain nut and lock washer and slotted head screws.

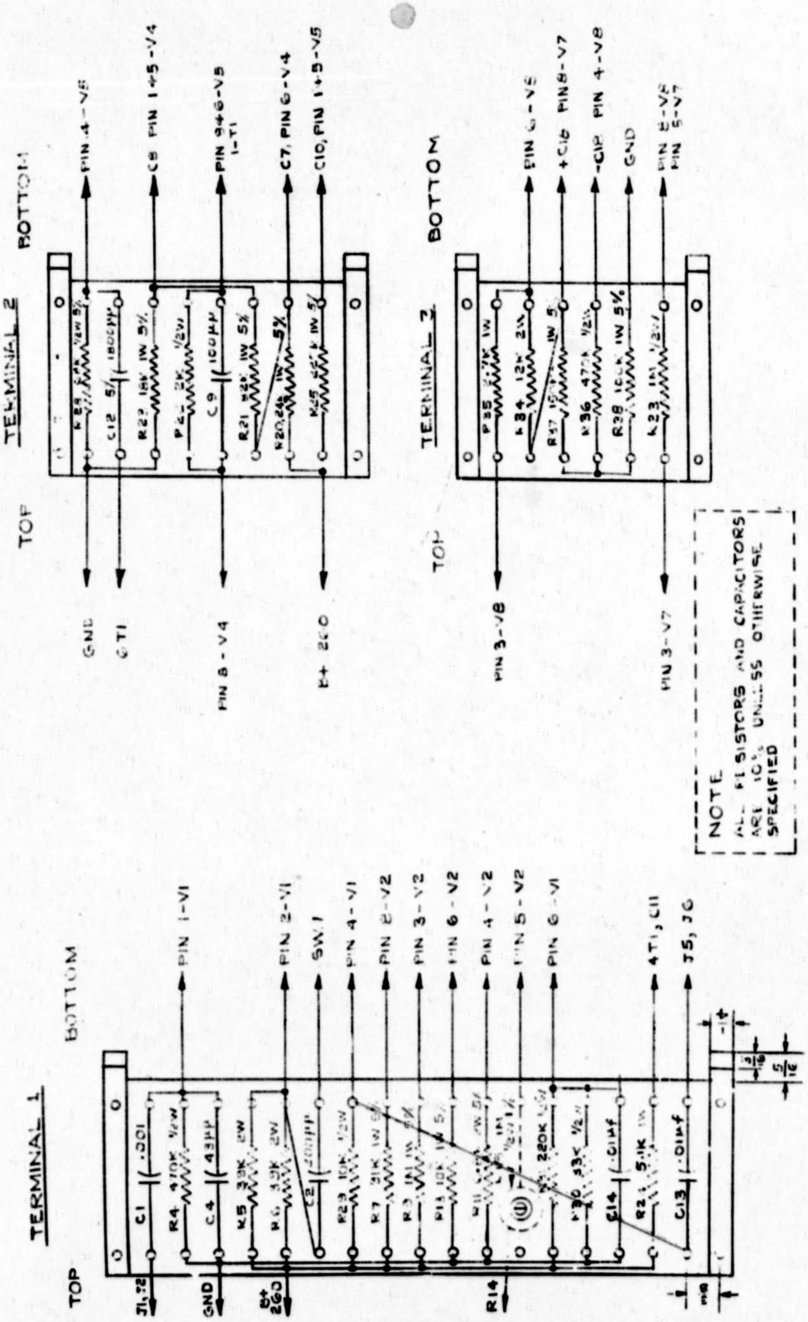
Mount potentiometer, R18, on 1/2 inch spacers, brass.

Terminal strips R.L. dwg. B13967C
Panel drilling layout R.L. dwg. B13967D
Chassis drilling layout R.L. dwg. B13967F

R. P. Abbenhouse
October 26, 1945



B-13967-A
GENERAL PURPOSE VARIABLE DELAY.



B-13967-C
G.P. DELAY UNIT TERMINAL STRIPS 1,2,3

REEL – C

4 8 3

A.T.I.

1 3 8 4 4

TSDIC FORM CO (13 MAR 47)

AUTHOR(S)		ATI- 13844
Abbenhaus, R. P.	DIVISION: Electronics (3) SECTION: Radar (2) CROSS REFERENCES: Delay apparatus, Variable (28896)	ORIG. AGENCY NUMBER: R-891 REVISION

AMER. TITLE: Description and operation of the general purpose variable delay unit

FORG'N. TITLE:

ORIGINATING AGENCY: Massachusetts Inst. of Technology, Radiation Lab., Cambridge

TRANSLATION:

COUNTRY	LANGUAGE	FORG'N.CLASS	U. S.CLASS.	DATE	PAGES	ILLUS.	FEATURES
U.S.	Eng.		Unclass.	Mar '46	18	10	photos, diagrs, graphs

ABSTRACT

This variable delay is a device designed for obtaining a trigger pulse delayed in time from an input trigger. The delay tima can be varied continuously from a fixad minimum value of about 10 microseconds to a maximum of about 2400 microseconds depending on the period between input triggers. The unit will accept a positive or negative trigger rising to at least 50 volts in 0.5 microsecond and supplies a positive or negative trigger output. It operates from a line voltage of 115 volts at 50 to 1200 cycles per second and will weigh approximately 20 pounds.